

DTIC FILE COPY

2

AD-A197 114

Front Cover

FUNDING NO. DAMD17-85-C-5083

**TITLE:** Operations and Management of Government Owned - Contractor Operated Microwave Exposure Facility

**SUBTITLE:** Effects of High Power Pulsed Microwaves on Rats Responding at High, Moderate, and Low Response Rates

**PRINCIPAL INVESTIGATOR**

Yahya Akyel, Ph.D.

**PI ADDRESS**

3211 Jermantown Rd.  
P.O. Box 10107  
Fairfax, VA 22030

**REPORT DATE**

February 28, 1988

DTIC  
SELECTED  
JUL 19 1988  
S D  
C&D

**TYPE OF REPORT**

Final - Volume 1

**PREPARED FOR:** US ARMY MEDICAL R & D COMMAND  
FT. DETRICK  
FREDERICK, MD 21701-5012

**DISTRIBUTION STATEMENT:**

Approved for public release, distribution unlimited

## REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS none			
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT approved for public release; distribution unlimited			
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S)		5. MONITORING ORGANIZATION REPORT NUMBER(S)			
6a. NAME OF PERFORMING ORGANIZATION ERCI Facilities Service Corp		6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION		
6c. ADDRESS (City, State, and ZIP Code)  3211 Jermantown Rd., P.O. Box 10107 Fairfax, VA 22030		7b. ADDRESS (City, State, and ZIP Code)			
8a. NAME OF FUNDING/SPONSORING ORGANIZATION US Army R + D Command		8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAMD17-85-C-5083		
8c. ADDRESS (City, State, and ZIP Code)  Fort Detrick Frederick, MD 21701-5012		10. SOURCE OF FUNDING NUMBERS			
		PROGRAM ELEMENT NO. 62777A	PROJECT NO. 3M1-6277 7A878	TASK NO. BB	WORK UNIT ACCESSION NO. 006
11. TITLE (Include Security Classification) Operations and Management of Government Owned- Contractor Operated Microwave Exposure Facility; Subtitle- Effects of High Power Pulsed Microwaves on Rats Responding at High, Moderate, and Low Response Rates					
12. PERSONAL AUTHOR(S) Yahya Akyel, Edward Hunt, Frank Bates, Chuck Gambrill, Carlos A. Vargas Jr.					
13a. TYPE OF REPORT Final- Volume 1	13b. TIME COVERED FROM 3/1/85 TO 2/1/88		14. DATE OF REPORT (Year, Month, Day) 1988 February 28	15. PAGE COUNT 26	
16. SUPPLEMENTARY NOTATION  Subtitle- Effects of High Power Pulsed Microwaves on Rats Responding at High, Moderate, and Low Response Rates					
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)			
FIELD 06 06	GROUP 18 02	18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)			
19. ABSTRACT (Continue on reverse if necessary and identify by block number) In recent years, the relationship between high peak power microwave irradiation and biological systems has generated considerable interest. The relative effects of microwave fields are a function of the exposure fields power density, and specific absorption rate (SAR). Behavior is just as important a determinant of change as is the RF field itself, however, sufficient characterization and comparison requires an analysis that extends over a range of behavior. Twelve male Wistar rats (245-260g) were hand shaped on three different schedules of reinforcement that generate distinct response patterns and rates from low to high. These schedules were: fixed-ratio(FR), differential reinforcement of low rates(DRL), and variable interval(VI). After training established stable baseline levels, rats were tested pre and post exposure for various microwave dose levels(including sham exposure). Four different microwave exposure levels have been studied, the average powers 4, 12, 36, and 108 watts correspond to whole-body average SARs of 2.8, 8.4, 25.2, and 75.6 W/kg, respectively. Exposure duration was 10 minutes; pulse width 10 microseconds, and the transmitter operated at 1MW peak power(1.25GHz)for all doses. Utilizing a corner reflector and					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL Mary Frances Bostian			22b. TELEPHONE (Include Area Code) 301-663-7325	22c. OFFICE SYMBOL SGRD-RMI-S	

19. rat holder (Gandhi, Hunt et.al. 1977-80), multilateral enhanced exposures gave temporal peak SAR of 7. MW/kg (0.7 W/kg/net transmitted power). This is one of the highest levels reported in the literature to date. Analysis of cumulative response records and video taped exposures failed to show any effects other than thermal for the various pulsed exposures when compared with equivalent average power exposures. This included the highest dose level (108W) which raised the rat's core temperatures up to 2.9 degrees C, and disrupted all activity. However, after approximately 10 minutes, an average decrease of 1.8 degrees allowed the animals to resume their schedules.

## FOREWORD

Opinions, interpretations, conclusions and recommendations are those of the author and are not necessarily endorsed by the U.S. Army.

14 Where copyrighted material is quoted, permission has been obtained to use such material.

14 Where material from documents designated for limited distribution is quoted, permission has been obtained to use the material.

(b)(1) Citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

~~Cff~~ In conducting research using animals, the investigator(s) adhered to the "Guide for the Care and Use of Laboratory Animals," prepared by the Committee on Care and Use of Laboratory Animals of the Institute of Laboratory Animal Resources, National Research Council (NIH Publication No. 86-23, Revised 1985).

11 For the protection of human subjects, the investigator(s) have adhered to policies of applicable Federal Law 45CFR46.

Accession For		
NTIS	CRA&I	<input checked="" type="checkbox"/>
DTIC	TAB	<input type="checkbox"/>
Unannounced		<input type="checkbox"/>
Justification		
<p>My</p> <p>Information</p> <p>is</p> <p>in</p> <p>my</p> <p>codebook</p> <p>and</p> <p>is</p> <p>not</p> <p>in</p> <p>any</p> <p>other</p> <p>place</p>		
<p>A-1</p>		

Cherry Hill 2/26/82  
PI Signature Date



## TABLE OF CONTENTS

1. Foreward.....	1
2. Table of Contents.....	2
3. Statement of the Problem and Rationale.....	3
4. Background and Review of the Literature.....	4
5. Materials and Experimental Method.....	5
6. Results.....	8
7. Discussion and Conclusion.....	10
8. References.....	22

### Tables and Figures

Table 1. Exposure Conditions and Power Levels....	14
Table 2. Exposure Order.....	15
Table 3. Temperature Rise.....	16
Figure 1. Baseline Performance.....	17
Figure 2. Post Exposure Performance.....	18
Figure 3. Percentage Change in RR and ORR.....	19
Figure 4. Mean Latency to Respond.....	20
Figure 5. Temperature Rise.....	21

## 1. Statement of the Problem and Rationale

In recent years the relationship between microwave irradiation and biological systems has generated considerable interest. Much of this interest has been focused on the effects of low level nonionizing radiation on the nervous system. These effects are often assessed through measurement of behavioral changes in organisms following exposure to continuous wave (CW) microwave irradiation. These experiments were most motivated by the studies of Eastern European scientists that reported a number of biological effects consequent to microwave radiation of animals, at power densities well below the current U.S. safety standard.

Guidelines (such as ANSI, NCRP, and EPA) developed subsequent to these experiments, afford protection from the presumed harmful effects of electric fields in tissue and the tissue heating that such microwave continuous wave fields induce. None of the guidelines address potential adverse health effects of high peak power pulsed microwave radiation. The U.S. Army, however, has become gravely concerned with the effects of high power pulsed microwave energy, since various generators and radar transmitters that are routinely used in their working environment produce pulsed microwave emissions.

The potential effects of high power pulsed microwave emissions on soldiers has stimulated a variety of studies on biological effects. Scientific research on the radio frequency (RF) biological effects is mostly based on physiological effects of microwave irradiation. However, behavior can serve as an index of how the entire organism is functioning, exhibiting the status of the nervous system and the many body organ systems as they act together. Behavior can be defined as the final common pathway of the nervous system, but it can be analyzed without resorting to surgically or biochemically invasive techniques.

The relative effects of microwave fields depend mostly on the exposure field, power density, and specific absorption rate (SAR). However, because behavior is just as important a determinant variable of change as is the RF field itself, sufficient characterization and comparison requires an analysis that extends over a range of behavior. The requisite for the present experiment develops the relationship between the two main aforementioned variables. Namely, the after effects of high power pulsed microwave radiation on adult Wistar rats, that have been trained to perform a lever pressing task requiring high, moderate, and low response rates, are studied.

## 2. Background and Review of the Literature

In behavioral psychopharmacology it has been found that when a behavior is being measured interactively with the administered dosage to determine a drug's effect, the rate at which this behavior occurs prior to drug administration is the key to characterizing the drug-behavior interaction. There is indeed a rate-dependency effect of the drug upon behavior. Various similarities exist between drug and microwave effects on biological systems; such as alteration of ongoing behavior, tolerance, and sensitization. The effects of the drugs depend on the drug dosage and concentration of the drug administered (Lai, Horita, Chou and Guy, 1987). Analogous to the dose-response relationship of drug action, the effects of microwave radiation should be a function of the SAR. The SAR-response function expression denotes the nature of the behavioral change induced by differing microwave doses.

Dews and Wenger (1977) found in their study that the effect of amphetamine is inversely related to baseline rates. It was found that when baseline rates are low, the behavioral change is generally incremental, but when the rates are high, the change is generally decremental. This pattern of rate-dependency and its effect upon behavior is present in much of the literature on microwaves. Thomas, Finch, Fulk, and Burch (1975) trained four Sprague-Dawley rats to respond on a multiple fixed-ratio and a differential reinforcement of low rates schedule. They discovered changes after 30 minute exposures to low level pulsed and continuous wave microwave fields; the rat's response rates increased on the differential reinforcement of low rates (DRL) component (which originally generates low response rates) and decreased on fixed-ratio (FR) component (which generates high response rates). Gage (1979) also found a decrease in the response rate of rats trained on FR schedules after overnight exposure to CW fields. Mitchell, Switzer, and Bronaugh (1977) found that rats exposed to 2450-MHz fields increased their response rate during the extinction period which normally generates a very low response rate during the baseline level.

Gage (1986) reported some contradictory results in his review of the behavioral studies in the RF field, an EPA report. He concluded that "there is no unifying hypothesis to explain all of the observed behavioral changes. There is ample evidence to suggest that microwaves alter a variety of unlearned and learned behaviors occurring during and after exposures. In most cases the behavior change can be described as a reduction in the level of ongoing activity." However, there have been some situations in which an increase in activity has been seen. The design of the present experiment studies effects that high power pulsed microwave fields have over a range of high and low behavior rates. This experiment attempts to show that high peak power

pulsed microwaves result in work disruption. Conversely, this work disruption is response-rate dependent on the subject as required by the different tasks.

### 3. Materials and Experimental Method

**Subjects:** Rodents have been used most frequently for investigating microwave radiation effects. Twelve male Wistar rats were used in this comparative study. Animals were maintained in a standardized environment at the Microwave Research Department at the Forest Glen Annex of WRAIR. The vivarium was maintained at 22 degrees centigrade, 50% relative humidity, under a 12-hour light-dark cycle, with the lights activated at 06:00. Rats were received from the National Institute of Cancer Research at 6 weeks of age. Upon arrival, the average weight of the animals was 144 grams. The first week the rats were maintained at the Forest Glen facility, they were allowed free food. When the experiment began, they were deprived of food for 16 hours before each experimental session. After Saturday's session, they were allowed to eat freely until Sunday afternoon. On Sunday afternoon the deprivation cycle was resumed. Water was freely available in their home-cages at all times. Feeding and care of these animals was performed by veterinary technicians on the Department of Microwave Research staff, following the procedures reviewed and approved by the Institutes's Laboratory Care and Use Committee.

**Apparatus:** The anechoic microwave chamber "A" in the Forest Glen facility was used to irradiate the animals. To enhance the effective power level of the exposure field, a corner reflector exposure system (Gandhi, Hunt, D'Andrea, 1977) was used. The animals were placed at a distance from the apex of the reflector where the reflections from the inside surfaces create maximum enhancement. A microwave transparent animal holder designed by Gandhi and Hunt (1980) was used to keep the animal's body axis parallel to the E-field. The ambient environmental conditions in the exposure chamber held at 22 degrees centigrade with a relative humidity of 50%. These temperatures were below the thermoneutral zone for Wistar rats (28-32°C) as reported by Poole and Stephenson (1977). However, the same authors also mentioned that the definition of thermoneutral zone is inappropriate. They indicate that at the temperature range in which metabolic rate is minimal, the rat is essentially heat stressed. The evidence for this heat stress is noted by the increased evaporation and the depressed locomotor activity of the animal. Both of these responses facilitate heat loss and reduce heat production which also are major intervening variables for microwave research. A low light level was maintained in the chamber in order to monitor the activities of the animal via a video recording system.

Behavioral testing was performed before and after microwave irradiation of the animals, in an operant chamber (Model # E10-10) from Coulbourn Instruments. This chamber was in an isolation cubicle (Model # E10-20) equipped with a ventilation fan. (A response lever (Model # E14-06) was used to deliver 45 mg dustless pellets manufactured by Bioserv Inc). The same environmental conditions (ambient temperature and humidity level) were also maintained in the operant chamber, which was located outside of the microwave exposure chamber.

The operant chamber was connected to an HP Vectra computer through a Metrabyte I/O interface card. Operant schedules were programmed in Compiled Basic Programming Language. A Ralph Gerbrands cumulative recorder was also used to collect visual data of the animals' performance. A Yellowspring analog thermometer was used to take rectal temperature readings from the animals.

**Dosimetry:** The average body weight of the rats' on exposure days were between 245.5 and 260.4 grams. Calorimetric measurements of whole-body specific absorption rates (SAR) were performed using carcasses of 246-250 g rats individually tested within the microwave exposure chamber "A." A single rat, placed in a styrofoam cylinder, in the usual exposure position inside the microwave transparent holder referenced in the apparatus section of this report. Carcass temperature was measured during microwave exposure using a Luxtron fiber-optic probe inserted into the animal's colon. During the dosimetry measurements, net power generated at the transmitting horn was 240 W. Carcass temperature was recorded via an HP Vectra/Data Translation (computer/data acquisition) system with a 5 reading per second sampling rate. The animal's heating curve showed a 38 millidegree centigrade increase per second. The temporal, whole-body average SAR calculation derived from the heating curve yielded a value of 0.7 W/kg per watt of antenna net transmitted power .

**Method:** Three different schedules of reinforcement that generate distinct response patterns and response rates from low to high were used. These schedules were fixed-ratio (FR), differential reinforcement of low rates (DRL), and variable-interval (VI). Fixed-ratio schedules produce a high rate of response in low ratio values. Differential reinforcement of low rates schedule requires one response after the delivery of the food reward. This response must be made after a predetermined amount of time elapses. Any response made before this time interval elapses resets the clock, consequently, DRL generates very low response rates due to this requirement. The third schedule was a variable-interval schedule that required only one response for the delivery of reinforcement after a variable amount of time had elapsed, but there was no punishment for other responses during

this time interval. The VI schedule produced a steady but moderate response rate. Random numbers for this schedule were generated by the computer. To get a new set of random values, a random-number generator was reseeded at the beginning of each session.

During the reinforcement cycle, stimulus and house lights were off and the reinforcement light was on for 3 seconds. Responses made during this interval did not have any effect on the schedule and every trial was followed by a 3 second extinction period. Post-reinforcement pause is defined as the time interval between the offset of the reinforcement light and the first response of the trial. The response time that was used to determine the local response rate is the time interval between the first and the last response of a trial.

After one week of adaptation, all of the subjects (7 weeks of age), were trained (hand-shaped) to press a lever as the behavioral requirement of the schedules. The lever was illuminated by a red light located above the lever. This shaping process lasted 8 days. Each of the three schedules were randomly assigned four rats. In other words, behaviors generated by each of the schedules were tested by using 4 rats after high power pulsed microwave exposure.

Experimental sessions were conducted 6 days a week. After the 8 day hand-shaping period, each schedule was introduced to the subjects at low values and the requirements of each schedule gradually increased. Within a week, all of the rats working on FR schedules reached FR 20, rats working on DRL schedule reached DRL 10 sec, and rats working on VI schedule reached VI 30 sec. Fixed-ratio DRL subjects received 50 reinforcements, VI rats received 40 reinforcements per session. All sessions lasted approximately 30 minutes. The order of training the animals was the same everyday. It started at 09:00 with FR animals followed by VI animals and terminated by DRL subjects. A steady baseline performance was established under these conditions in 2 weeks. The stability of the baseline was determined by visual inspection of the cumulative recordings, and the response rate was expected to be within 10% of the previous day's data for three days in a row.

Four different microwave exposure levels were used. Exposure duration was 10 minutes, pulse width was 10 microseconds, and the transmitter was operating at a 1 MWatt peak power level for all of the conditions. Whole-body dose-rate levels were adjusted by using different pulse repetition rates. During the ten minute period, 240, 720, 2160, and 6480 pulses were used for the various dose rate levels, corresponding to 4, 12, 36, and 108 watts radiated average power. Hereinafter, the dose levels will refer to the average radiated power delivered to

the transmitting antenna; such as 4, 12, 36, and 108 watts. The dose levels and the corresponding values are summarized in table 1.

Each animal was exposed to a different dose level each week in a random order. Each animal received every dose rate over the duration of the project (Table 2), for a total of 4 sessions of irradiation. Exposures were done on Saturdays. Following each exposure, the rats were transferred immediately to the experimental chamber, and the schedule of reinforcement that they had been trained on was started. The onset of the operant schedule, followed the termination of irradiation by less than 80 seconds. This is the lowest reported value for any published research that studied after-effects of microwave radiation. After Saturday's experimental sessions, the animals were put on free-food diets until late the next day. They were not put on a schedule of reinforcement during this time. These animals were sham exposed twice, using the same procedure described above, both without any microwave exposure.

Physiological monitoring was conducted using 9 animals, three from each reinforcement schedule. Individual animals from each schedule were exposed under one of three conditions: 1) Sham exposure (placed in reflector, no irradiation), 2) Exposed to 36 W of radiated power and, 3) Exposed to 108 W of radiated power. Rectal temperatures were taken before the exposure and immediately following exposure (within 120 seconds) for the sham and 36 W groups. Temperatures, following the 108 W exposures, were taken as soon as they began responding, pushing the lever, or after 10 minutes. At the end of the experiment, animals were euthanized with an overdose of pentobarbital.

#### 4. Results

All of the subjects performed as expected at their baseline levels of their reinforcement schedule. A sample of cumulative recordings is presented in Figure 1. Fixed-ratio subjects showed a high response rate, depicted by a high slope of the cumulative recording, that was sustained until reinforcement occurred. This was followed with a pause (called a post-reinforcement pause). Variable interval subjects showed a steady but moderate response rate which is depicted by a slope that is less than that of the FR animals. However, steady pauses after the reinforcements (as seen in FR schedules) were rare. Differential reinforcement of low rate animals also occurred as expected. Rats in general are much better performers in DRL schedules than other animals (Millenson and Leslie, 1979). Cumulative recordings of this schedule show the lowest slope and lowest response rate among the three schedules.

Post exposure performance of the animals trained on these schedules is presented in Figure 2. The characteristic response pattern of the schedules did not show any changes. Rats trained on FR schedules exposed to high power pulsed microwave fields still showed the same pattern of responding, with the highest response rate among the animals on different schedules; and also displayed pauses after the reinforcements, a characteristic behavior of FR schedules. Animals trained on DRL schedules, kept their low rate of responding pattern after the exposures, and the animals trained on VI schedules were still responding moderately. In other words, the order of response rate and the pattern of responding among the remained constant after exposure to the microwave fields regardless of the dose level.

The overall response rate (ORR) and response rate (RR) (local rate) decreased after exposure to the 108 W condition for all of the animals except for the RR of the DRL animals. In this report ORR is defined as the rate of responding during the experimental session including all of the pauses. On the other hand, response rate or local rate is calculated by dividing the total number of responses by the experimental session duration, excluding all of the pauses. Overall response rate indicates the rate of responding, because it excludes pauses and defines the rate of responding between the first and last trial.

Figure 3 represents percentage change of the response rate (RR) and the overall response rate (ORR) from the control sessions (last three sessions before the exposure session). The data is presented in terms of mean response rate and mean overall response rate of the animals in each schedule group (after being exposed to 4, 12, and 36 W exposure conditions) for ORR and RR. For the highest dose level (108 W exposure condition) the decrease in ORR is between 65 and 75% with a smaller decrement in RR calculations. After the exposure to 108 W, the response rate decreased only 29% for FR animals, 52% for VI animals, and it increased an average of 22% for DRL animals.

This data shows that after being exposed to 108 W, the animals decreased their overall response rate throughout the session, but their response rate between the first and the last response of each trial did not change drastically. Based on this data we can conclude that the animals increased their pauses after the delivery of the reinforcement (since ORR includes pauses in its calculation), but their response pattern, which was represented by RR calculation did not change as much as the ORR. Observation of the next figure (Figure 4) shows that after being exposed to the highest dose level, the animals started to press the response lever, an average of 13 minutes after exposure. There is no significant difference in the mean latency to respond among different schedules.

Analysis of the data collected from the rectal temperature readings, before, immediately after, and ten minutes after sham and microwave exposures is presented in Figure 5. Rectal temperature of sham exposed rats showed no significant change before, immediately after, and ten minutes after the exposure. Rectal temperature of the animals exposed to the 36 W condition increased an average of 0.7 degrees centigrade. The temperature data showed no significant change after ten minutes for this group. Rectal temperature of the rats exposed to 108 W however, increased 2.5 degrees centigrade. It should be noted that these animals did not make any lever pressing responses for 13 minutes on the average, as noted in the previous paragraphs. Their temperatures were recorded as soon as they began pressing the response lever. The second recording of the rectal temperature was done approximately 10 minutes after the termination of the microwave exposure. At this second reading, a decrease of 1.8 degrees centigrade is observed. Ten minutes after the exposure, mean rectal temperature readings of the animals exposed to microwave radiation at 36 and 108 W were 37.4 and 37.6 degrees centigrade respectively. Table 3 represents actual temperature readings from individual animals.

Video tape recordings of the animals during the exposure showed that the animals exposed to 4, 12, and 36 watts did not show any abnormal behaviors which can be interpreted as stressful to the animal, such as urination, defecation, or increased evaporation of body fluids (as evinced by matting of the fur). However, all of these distress symptoms were observed for the highest dose level, the 108 W exposure. The animals in this group, unlike the animals exposed to lower dose levels, did not begin responding immediately upon placement in the chamber. The animals in this group remained in one corner of the operant chamber, elongated their bodies, and showed no locomotor activity for an average of 13 minutes. When they began responding, their response patterns were similar to the animals that were exposed at lower dose levels.

##### 5. Discussion and Conclusion

The results of the present study were informative in several ways. First, high SAR values and consistent, reliable colonic temperature increases observed after the exposures proved that the exposure system used in this study is very reliable. Two methods were used to increase the effectiveness of our exposure system. First, to enhance the effective power level of our exposure system, a corner reflector was used. Instead of simply being located in the far field of radiation horn to be exposed unilaterally, the rat was located inside of the corner reflector at a distance at which the reflections from the inside surfaces created a multilateral field enhancement. The second method utilized was a microwave transparent animal holder for keeping

the animal parallel to the E-field. The orientation of the animal, with its long axis parallel to the plane of the E-field, maximized the efficiency with which the energy is absorbed from the enhancement region.

Whole-body average specific absorption rate, (SAR), which is the rate at which energy is absorbed into the tissue, was 0.7 W/kg per watt of net radiated power. The SAR was determined in an insulated cadaver. The resulting effect in live rats was as follows: The increase in the rectal temperature of the animals exposed to 36 and 108 W were consistent among subjects. Average temperature of three rats in the 36 W group increased from 36.7 to 37.3 degrees centigrade with a standard deviation of only 0.2. For the 108 W group, (75.6 W/kg) the temperature rose 2.9 degrees centigrade. The temporal peak whole-body average SAR was 0.7 MW/kg, this value is one of the highest reported in the literature.

Another successful point of the present study was the use of operant conditioning behavioral techniques. In general, behavioral techniques can be used to address a variety of end points that range from sensory physiology to higher mental processes: learning, memory, judgement, and thought. On the other hand, in operant conditioning the occurrence of the response is assured. The response is directly elicited by the unconditional stimulus, (the light above the response lever) which is controlled by the investigator. Reinforcers given after the first emission of the response readily maintain a locomotor operant, which was a lever press response in this case. The animal is free to press the lever by any means. However, the investigator determines the temporal relations among stimuli, response, and the delivery of reinforcers (food pellets). An effective schedule results in a consistent pattern of responding.

Schedules of reinforcements used in this study resulted in three different patterns of responding that ranged from a low to a high rate of responding. Furthermore, animals retained these specific patterns of responding even after being exposed to very high dose levels. This fact supports the effectiveness and appropriateness of using operant reinforcement schedules in studying the effects of microwave exposure on behavior. Operant schedules can mimic the tasks that a soldier is required to execute during a combat situation in front of a radar transmitter or in other situations that expose the soldier to microwave radiation with high peak powers.

This experiment, unlike the other microwave experiments that study lethal effects of RF fields, was carefully designed and executed in order not to kill the animals. The rats used in this experiment were trained to perform certain tasks in a prescribed manner, and to perform said tasks after being exposed to pulsed microwave radiation. In the literature it has been reported that

a rise of core temperature to 43 degrees centigrade is lethal to rodents (Shrot and Hawkins, 1976). deLorge and Ezell (1980) reported that a one degree centigrade increment in the core temperature results in work disturbance. The present experiment resulted in a rise of as much as 2.9 degrees centigrade, which is close to lethal dosage, and almost three times higher than the reported work disturbance temperature rise. The important point is that the animals that have been exposed to such high dose levels were still able to perform their tasks after a relatively brief period of rest (13 minutes on the average). Another point to be noted is that none of the animals showed any permanent behavioral effects after the exposures. Their food and water intake and their performance remained constant until the termination of the experiment. For some of the animals, this was as much as six weeks after being exposed to the highest dose level. The second highest dose level induced a temperature elevation that was less than the rise associated with the established work disturbance. Our pulsed microwave experiment confirmed this fact, as the 36 W dose with a 0.7 degree centigrade temperature rise did not result in any behavioral effects. Therefore, the pulsed nature of the exposures did not produce responses that were different from CW effects reported by others.

The analysis of the response rate and overall response rate data did not show the effect that we expected based on the psychopharmacological experiments. Rate dependency effect was absent from the data. However, another interesting result emerged from the analysis. Animals working the DRL schedule performed better after the exposure to 108 W. But this can not be interpreted as an effect where the microwave exposures yielded better performance. The nature of the DRL schedule requires a low response rate, the animals exposed to microwave fields decreased their response rate in general; thus this decrease resulted in better performance (i.e., less responses per reinforcer). The main reason for the absence of rate dependency paradigm was the high exposure levels. As noted earlier, the highest dose level was close to lethal dosage and proved to be effective. The second highest dose did not increase the animal's core temperature sufficiently to cause a change in responses.

Based on the results obtained from the rectal temperature readings of the animals exposed to RF fields, we can conclude that the behavioral effects that we have seen were thermal in nature and were independent of the pulsed nature of the exposure fields. As soon as the elevated rectal temperature of the animals dropped by 1.5-2.0 degrees centigrade, they began to press the response lever effectively. The temperature reading at this point was close to the post exposure temperature reading of the animals that did not show any work disturbance (36 W exposures). The behavioral paradigm utilized in this experiment proved to be successful and offers a new and reliable dependent

variable that can be tested by using microwave fields as the independent variable. The rate dependency effect of the RF fields could not be observed in this experiment, but a range of dose levels where this effect may be seen, has been estimated as a result of this study. These dose rates lie between 25.2 W/kg and 75.6 W/kg (average whole-body).

Besides these results, the present experiment also showed the effectiveness and the reliability of the exposure system used by the Department of Microwave Research. SAR value obtained from the system, and the ability to expose animals 6 weeks in a row proved that with adequate engineering support, this high peak power system (that is very susceptible to many kinds of breakdowns) can be maintained to provide effective and reliable irradiation capabilities. However, the absence of any measurable non-thermal effects from the high power pulsed microwaves, justifies extending the experimental pulsed parameters. Various pulse width and/or pulse intensity exposures, with CW exposure of equivalent average power, will be performed in the future. These experiments should determine whether the peak (rather than the average) power of pulsed microwaves influence the effects observed following exposure. A new protocol investigating the similar paradigm, prepared by the principal investigator of this report, will be presented to the Walter Reed Army Institute of Research for a review. Another area of interest that this report generated is the study tolerance to microwave fields. The latency to the start of the response of the animals when exposed to the highest dose is a very reliable paradigm that will help us to study any tolerance developed to microwave exposures. If the animals develop a tolerance to RF fields, this latency should decrease after each subsequent exposure. An experiment designed to study this question will also be presented by the same principal investigator to the Department of Microwave Research.

TABLE 1

Exposure Conditions (\*) and Corresponding Average Whole-Body Dose-Rates

Average Power Radiated (watts)	# of Pulses	Hz	SAR W/kg
4	240	0.4	2.8
12	720	1.2	8.4
36	2160	3.6	25.2
108	6480	10.8	75.6

(\*) In all exposure conditions the Microwave Transmitter (Cober) was operated at 1 MWatt peak power level. The duration of the pulses was 10 microseconds and the duration of the exposure was 10 minutes.

TABLE 2

Order of the Various Exposure Levels for Each Animal

<u>Subjects</u>	<u>Schedule</u>	Exposure Levels (Watts)			
		<u>1st</u>	<u>2nd</u>	<u>3rd</u>	<u>4th</u>
R-11	FR	36	4	12	108
R-12	FR	12	108	36	4
R-13	FR	4	12	108	36
R-14	FR	36	4	108	12
R-15	VI	36	108	4	12
R-16	VI	12	4	36	108
R-17	VI	4	108	12	36
R-18	VI	36	12	4	108
R-19	DRL	36	12	4	108
R-20	DRL	4	36	12	108
R-21	DRL	4	108	36	12
R-22	DRL	12	108	36	4

TABLE 3

## Pre and Post Exposure Temperature Rise of Individual Animals

<u>Subject/Exposure Level</u>		Temperatures		
		<u>Before</u>	<u>After</u>	<u>After 10 min</u>
R-11	36 W	36.7	37.3	37.3
R-16	36 W	36.7	37.3	37.4
R-20	36 W	36.6	37.4	37.4
R-13	108 W	37.2	39.5	37.4
R-17	108 W	36.8	39.1	37.6
R-22	108 W	36.6	39.5	37.7
R-12	sham	37.2	37.2	37.2
R-18	sham	37.2	37.3	37.3
R-19	sham	36.5	37.1	37.0

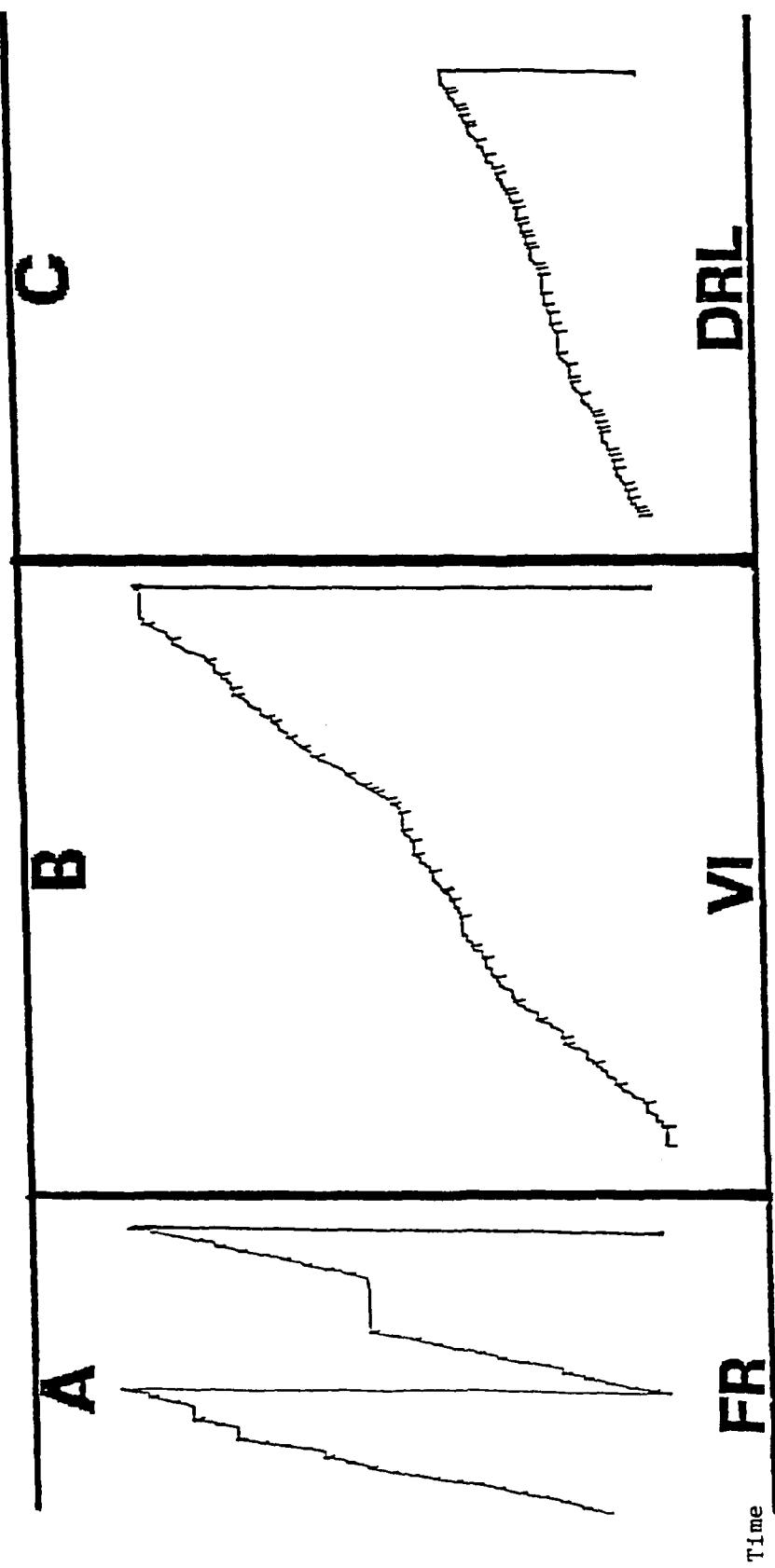


FIGURE 1. Baseline cumulative recordings of the animals performing at A) Fixed Ratio (FR), B) Variable Interval (VI), and C) Differential Reinforcement of Low Rates (DRL) Schedules.

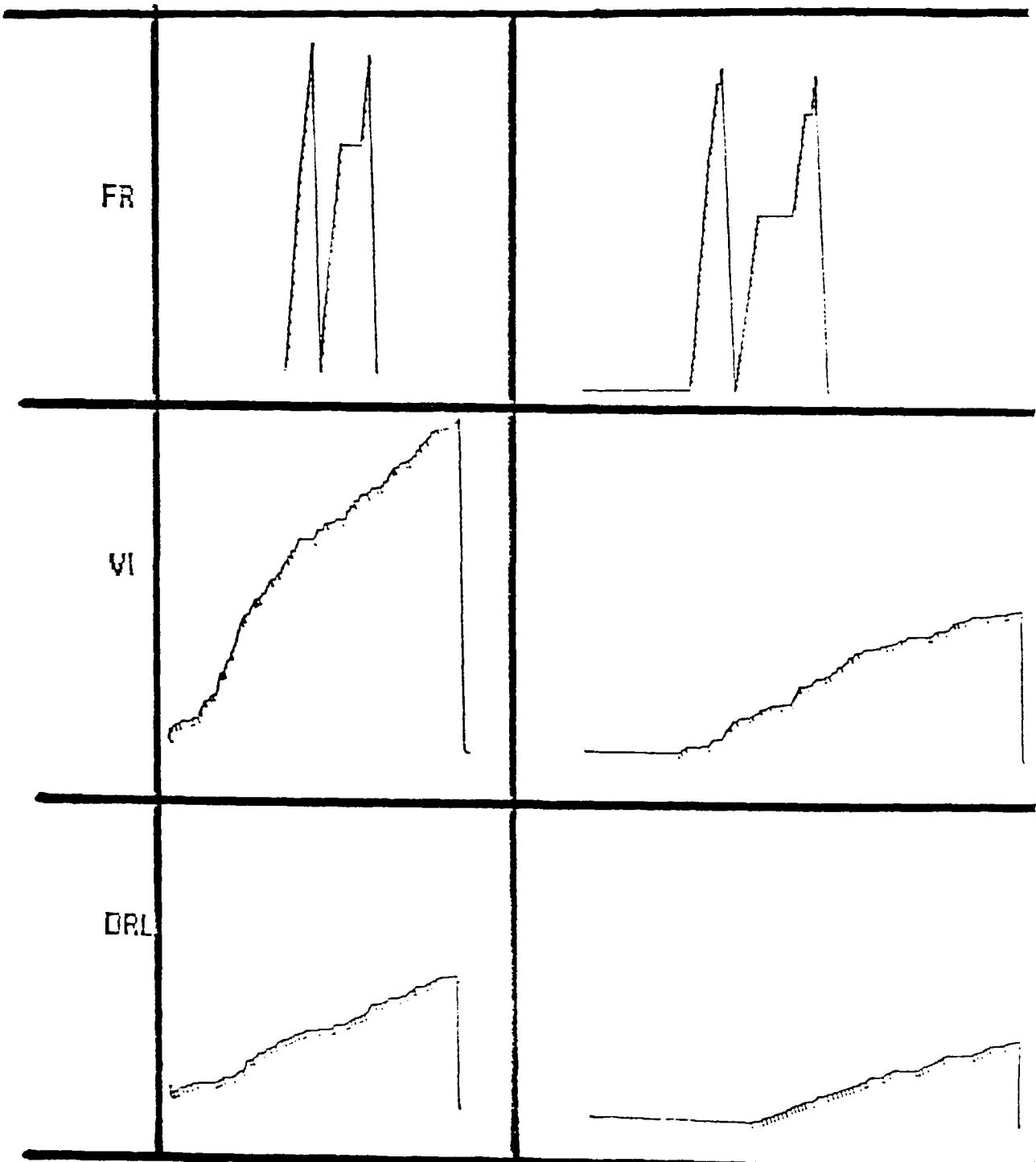
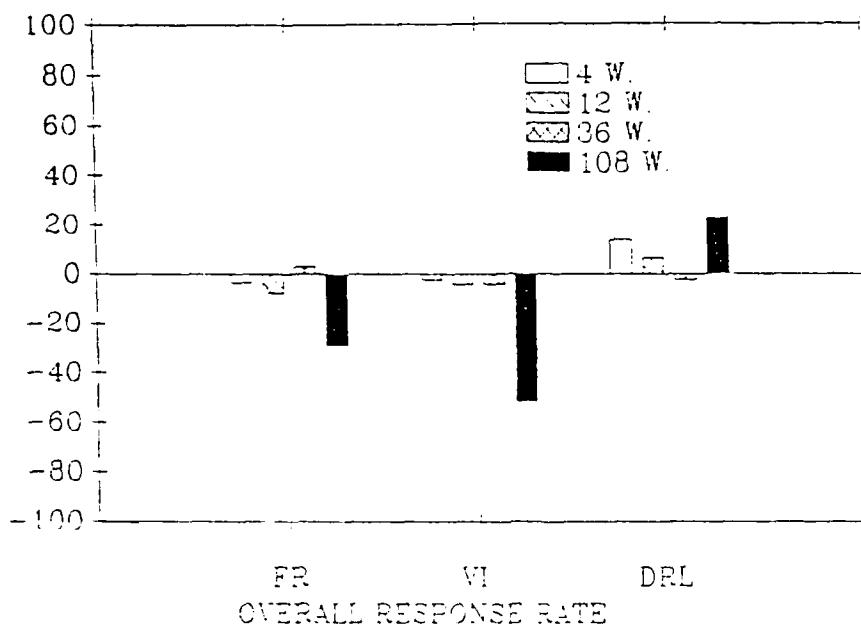


Figure 2. Post-exposure cumulative recordings of the animals from 36W and 108W groups. Y-axis denotes responses, X-axis denotes time.

### RESPONSE RATE



### OVERALL RESPONSE RATE

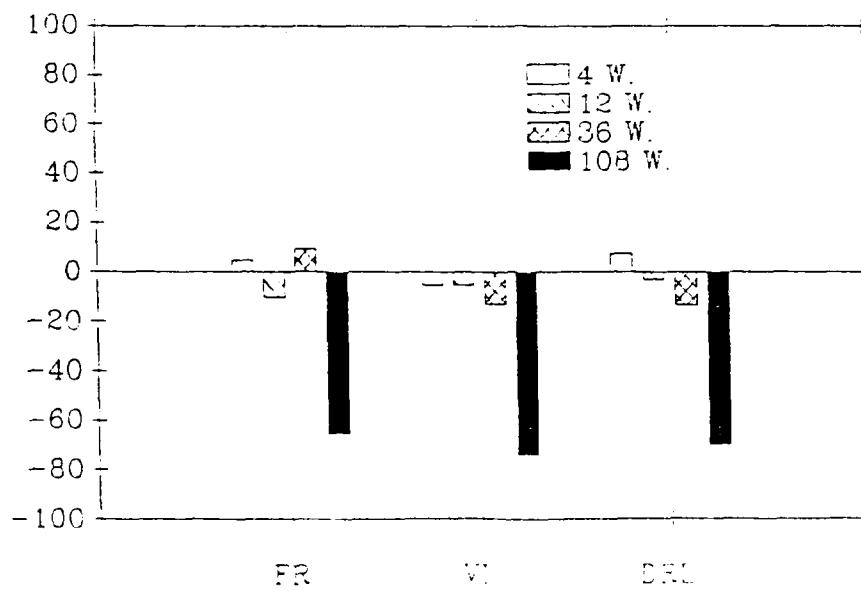


Figure 3. Percentage change of the response rate(RR) and overall response rate(ORR) from the control sessions. Control sessions were the last three sessions before the exposure. Y-axis denotes the change, X-axis denotes three different schedules of reinforcement. Each bar represents a different exposure level.

MEAN LATENCY AFTER 108 W.

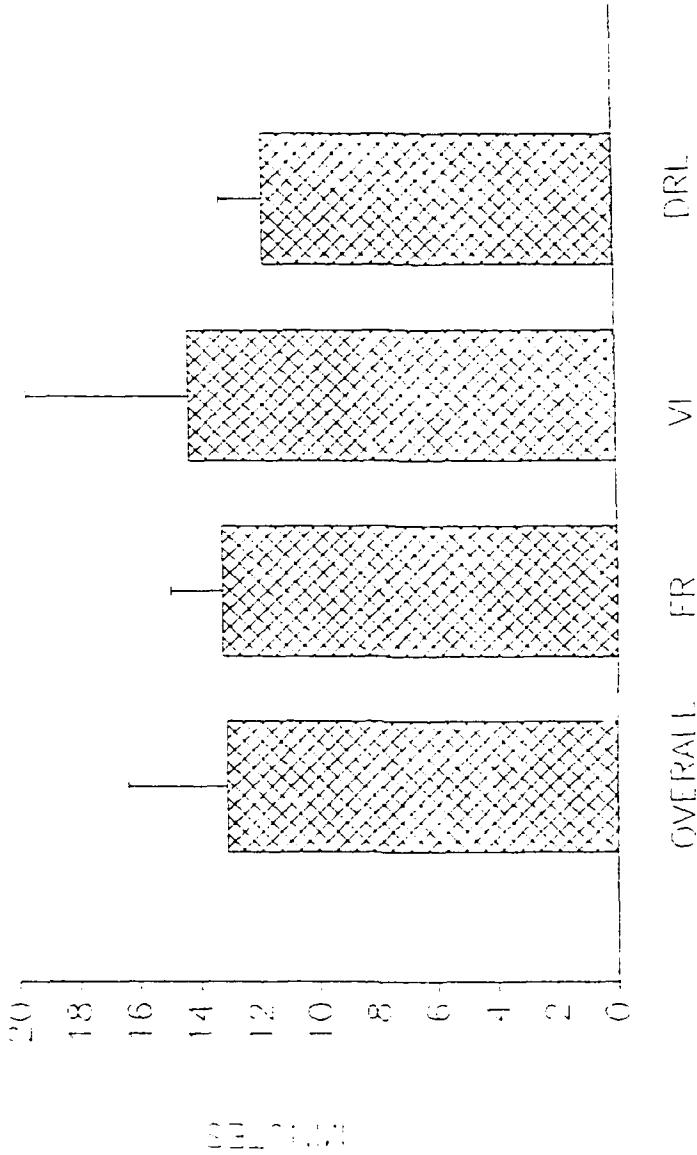


Figure 4. Mean latency to start to press the response lever after being exposed to 108 watts. Y-axis denotes time in minutes, X-axis denotes the mean latency of all the subjects exposed to 108 W (overall) and mean latency by schedule of reinforcement. Thin lines above the graphs denote standard deviations.

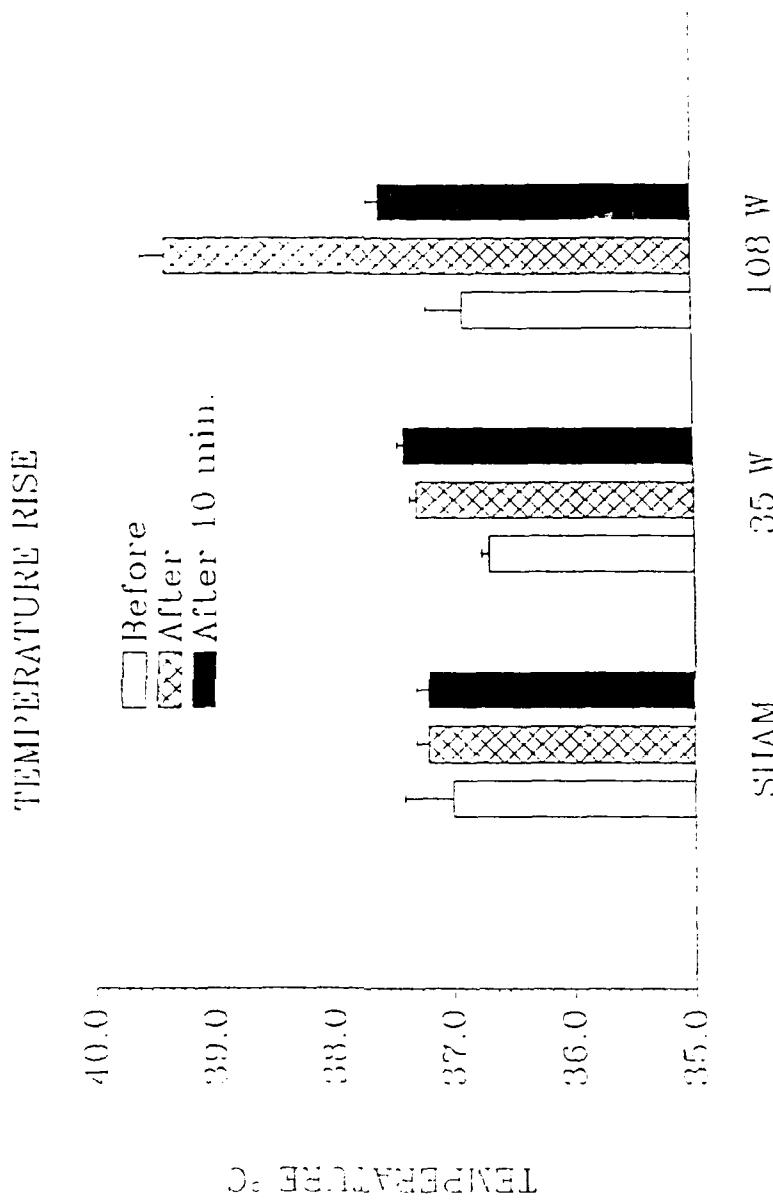


Figure 5. Rectal temperature rise in degrees centigrade of the animals before, after, and 10 minutes after the exposure to 36 and 108 W exposure levels. Y-axis denotes temperature rise in degrees centigrade, and X-axis denotes the different exposure conditions. Thin lines above the bars denote standard deviations.

## REFERENCES

ANSI (1982) Safety levels with respect to human exposures to radio frequency electromagnetic fields, 300 KHz to 100 GHz, Report # ANSI C95. 1-1982, IEEE New York

deLorge, J.O., and Ezell, C.S. (1980) Observing response of rats exposed to 1.28- and 5.62-GHz microwaves. Bioelectromagnetics, 1, 183-198.

Dews, P.B. and Wenger, G.R. (1977) Rate dependency of the behavioral effects of amphetamine. In T. Thompson, and P.B. Dews (Eds.) Advances in Behavioral Pharmacology, Vol 1. New York: Academic Press.

EPA (1986) Federal radiation protection guidance; proposed alternatives for controlling public exposure to radiofrequency radiation, Federal Register, 51, 146.

Gage, M. (1979) Behavior in rats after exposure to various power densities of 2450 MHz microwaves. Neurobehavioral Toxicology, 1, 137-143.

Gandhi, O.P., Hunt, E.L., and D'Andrea, J.A. (1977) Deposition of electromagnetic energy in animals and in models of man with and without grounding reflector effects. Radio Sciences, 12, 39-45.

Gandhi, O.P., Hunt, E.L. (1980) Corner-reflector applicators for unilateral exposure of animals in bioefffect experiments. Proceeds of IEEE, 68, 160-162.

Lai, H., Horita, A., Chou, C.K., and Guy, A.W. (1987) A review of microwave irradiation and actions of psychoactive drugs. IEEE Engineering in Medicine and Biology Magazine. March, 31-36.

Millenson, J.R. and Leslie, J.C. (1979) Principles of Behavioral Analysis. New York: Macmillan Publ. Co.

Mitchell, D.S., Switzer, W.G., and Bronaugh, E.L. (1977) Hyperactivity and disruption of operant behavior in rats after multiple exposure to microwave radiation. Radio Sciences, 12, 26-27.

NCRP (1986) Biological effects and exposure criteria for radiofrequency electromagnetic fields, NCRP Report # 86, National Council on Radiation Protection Measurements, Bethesda, MD

Poole, S. and Stephenson, J. (1977) Body temperature regulation

and thermoneutrality in rats. Quarterly Journal of Physiology and Cognitive Medical Sciences. 62, 143-149.

Schrot, J. and Hawkins, T.D. (1976) Interactions of microwave frequency and polarization with animal size. In Johnson, C.C. and Shore, M.L. (Eds.) Biological Effects of Electromagnetic Waves. HEW Publication # FDA 77-810 (Government Printing Office, Washington, D.C.)

Thomas, J.R., Finch, E.D., Fulk, D.W., and Burch, L.S. (1975) Effects of low-level microwave irradiation on behavioral baselines. Annals of New York Academy of Sciences. 247, 425-432.